Decision-Making and Long-Lead Climate Forecasts

A Case Study in Community Water System Management

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I. Preliminary Materials

A. Project Abstract

The successful predictions of the 1997-98 El Niño and subsequent La Niña have heightened interest in the use of long-lead climate forecasts for socioeconomic decision-making. We hypothesize that this type of information should be particularly valuable in community water system (CWS) management where climate is believed to be a fundamental consideration. Decisions that CWS managers make in their medium- and long-range planning could incorporate climate information to minimize disruption and to take advantage of the opportunities provided by nature. Preliminary research suggests, however, that these managers generally do not incorporate climate forecasts in planning.

Consequently, the proposed research addresses the questions: (1) How do CWS managers anticipate and adjust to severe weather events and climate variation? (2) How could improved long-lead climate information enhance the ability of CWS managers to adjust to these phenomena and reduce sensitivity and vulnerability? (3) What are the barriers to incorporating forecast information into planning? (4) How does the confidence of CWS managers in the climate forecast affect the usefulness or implementation of the information? (5) In what forms of presentation, as well as types of measures extracted from the forecast, can this information be communicated to CWS managers most effectively?

The research primarily involves focus groups, a mail survey, and interviews involving CWS managers. The focus groups guide and ensure quality surveys. The survey seeks to determine CWS managers' opinions of forecasts and why they fail to use climate-forecast information. The interviews attempt to answer questions left unanswered by the survey, to understand CWS vulnerabilities and how managers address those vulnerabilities, and to gain a more complete understanding of the kinds of weather and climate information they need for planning and operations. The goal of this research design is to identify the kinds of climate-forecast information that CWS managers need to protect water supplies and deliver safe drinking water to their customers.

There are two unique features of the research. First, previous work on climate forecasts and water management has focused on the western United States, with its distinct climatic and water management regimes. This research concentrates on the eastern United States, which has fundamentally different where climates and management systems. The second exceptional feature of the research is the comparison of results from South Carolina and the Pennsylvania portion of the Susquehanna River Basin (Pennsylvania SRB). This comparative research studies differences in regional climatic sensitivity and CWS management to develop a more robust understanding of the present and potential use of climate forecasts in varying contexts.

The investigators request a one-year, no-cost extension to this grant (see section III.D. for details).

B. Objectives of the Research

Because weather and climate are significant hazards to CWSs and are fundamental to their operations, it appears that CWS managers could incorporate weather and climate information in their short-, medium-, and long-range planning to minimize disruptions, insure safe water supplies, and schedule day-to-day and season-to-season activities. We do not know, however, to what extent these managers perceive risks associated with weather and climate or recognize the benefits of using weather and climate information in their operations and planning. We are also interested in learning how managers respond to probabilistic information and what types of risk they view as acceptable within their systems. Consequently, this research project addresses several questions. (1) Do CWS managers anticipate and adjust to severe weather and climate variation? (2) Could improved long-lead climate information enhance the ability of CWS managers to adjust to these phenomena and to reduce sensitivity and vulnerability? (3) What are the barriers to incorporating forecast information into planning? (4) How does the confidence of CWS managers in the climate forecast affect the usefulness or implementation of the information? (5) What measures and what presentation formats can communicate forecast information to CWS managers most effectively?

C. Approach

The research features a comparison of results from the Pennsylvania SRB and South Carolina. The comparative analysis incorporates regional differences in sensitivity to weather and climate and in water management issues to facilitate a better understanding of climate forecast use among CWS managers.

To answer the questions posed in I.B., above, we have been eliciting information from CWS managers in both states in the following sequence. First, we conducted focus groups with managers from medium-sized and large systems and then from small systems to develop a knowledge base for the formal mail survey.

The surveys had four sections. The first sought to find out how CWS managers view forecasts in general and if they use weather and climate forecasts in their planning and operations. The second section aimed at determining system sensitivity and vulnerability to weather and climate. The third tried to establish the ability of the managers to understand and use climate forecasts. The fourth section gathered basic information on characteristics of the managers and their systems.

We used a modified Dillman method to conduct the surveys. We arranged for the Pennsylvania and South Carolina branches of the American Water Works Association to provide an advance letter on association stationary that we mailed to all members in the study areas—mainly managers of large systems. Similarly, we had the Pennsylvania Rural Water Association and South Carolina Rural Water Association supply advance letters for their members—primarily managers of small systems. About one week after we mailed the advance letters, we mailed the cover letters, surveys, and stamped return envelopes to all CWS in both

study areas. One week later, we mailed reminder post cards to all managers. Three weeks later, we mailed second sets of surveys and envelopes to those systems that had not yet responded. In all, we mailed 784 surveys in the Pennsylvania SRB and 527 surveys in South Carolina. We concluded the process with 405 valid surveys (a 52 percent response rate) in Pennsylvania and 269 valid surveys (a 51 percent response rate) in South Carolina.

The final phase of research (Summer 2002-Summer 2003) will focus on interviewing all managers of large CWSs in the Pennsylvania SRB. This population of nearly 20 systems provides water to most of the people in the basin; all but two systems receive their supplies from surface water, so we hypothesize that these managers make similar operational and planning decisions and have similar needs for climate forecast information. The interviews will determine which decisions could benefit from climate forecast information, what time of year they make these decisions, and how much lead time each of these decisions require. From this information, we will work with the managers to develop climate forecasts specifically tuned to these decisions. We will include a tool we have developed that produces forecasts of the Palmer drought severity index (PDSI) from standard NOAA temperature and precipitation climate forecasts. It is still an open question to what degree they can use climate forecasts.

D. Matching Funds

There are no formal matching funds from Penn State or the University of South Carolina. Elements of this research, however, complement an earlier project concerned with global warming impacts on water resources in the SRB and funded by EPA, so some of the work performed for that grant has contributed to this research. Furthermore, this work contributes to the Human-Environment Regional Observatory (HERO) project funded by NSF and NOAA's Human Dimensions of Global Change Research Program, so HERO funds have helped cover costs incurred on this research.

II. Interactions

A. Interactions with Decision-Makers

We have had intense interactions with CWS managers throughout the project in both the Pennsylvania SRB and South Carolina. In both study areas, we have toured systems of various sizes and types, conducted focus groups, administered mail surveys, and interviewed CWS managers. Before this project, we held two focus groups and surveyed all CWS managers in the Pennsylvania SRB about their perceptions of global warming and its impacts on their activities. We mailed thank you notes and copies of the publication that resulted from the pilot study to participants in the two focus groups. We also sent thank you letters to the approximately 800

CWS managers in the study area and included results from the pilot research. The thank you letter contained two paragraphs that discussed the NOAA project and said that we would be contacting them in the coming months for help in developing climate forecast information that better meets the needs of CWS managers. In both cases, we received notes and telephone calls expressing appreciation for these follow-ups.

An important part of the project has been working with representatives of professional associations representing large urban systems (the Pennsylvania and South Carolina branches of the American Water Works Association) and small rural systems (the state branches of the American Rural Water Association). The purpose of this work was to establish trust with the states' water professionals. We have interacted with other related stakeholders, as well. For example, in Pennsylvania, we met with the Water Systems Coordinator of the Centre County Planning Department to discuss the NOAA project and to enlist his support in working with managers of the smallest, most rural systems, who are often hesitant to meet with outsiders. In South Carolina, we contacted professional water resource managers representing the SC Department of Health and Environmental Control, the SC Department of Natural Resources, and the state office of the United States Geological Survey. These groups have all been willing to help and share data.

B. Interactions with Climate Forecasting Community

Interaction with the climate forecasting community has been limited to this point in the research. The focus continues to be on water managers—especially CWS managers.

C. Coordination with Other NOAA Climate and Societal Interactions Division projects

To this point in the research, our interaction with other NOAA Climate and Societal Interactions Division projects has been limited to email discussions and casual meetings at conferences. It is important to note, however, that this project is collaboration between Penn State and the University of South Carolina. It has entailed constant interaction between Pennsylvania and South Carolina team members by phone and email, as well as rendezvous at national meetings and reciprocal visits to each study area.

In the upcoming year, we anticipate coordinating with other NOAA researchers working on climate forecasts and water management issues. Specifically, we plan to compare our results for eastern water managers to the findings of the groups working in the arid Great Plains (John Wiener and colleagues at the University of Colorado) and the arid Southwest (Holly Hartmann, Thomas Pagano, and others at the University of Arizona). We are hoping that we can develop a clear picture of the nature of water management, water managers, and climate forecasts (and perhaps a publication) from this interaction. We also plan to consult with Hartmann and

Pagano about ways to design climate forecast products for Pennsylvania and South Carolina CWS managers. Their recent research (see Hartmann et al., *Bulletin of the AMS*, 83:683-698) on developing user-based climate forecasts precludes some of the work we intended to do and allows us to work with our stakeholders to customize forecasts for their needs.

III. Accomplishments

A. Research Tasks Accomplished

The major research task accomplished to date was the CWS manager survey. As noted above, the process yielded 405 valid surveys (a 52 percent response rate) from the Pennsylvania SRB and 269 valid surveys (a 51 percent response rate) from South Carolina. There were small differences between the Pennsylvania SRB and South Carolina versions to account for regional contexts (e.g., cover graphics), but nothing that compromised the comparability of the results. A digital copy of the Pennsylvania SRB survey is attached to this submission as an appendix.

The survey had four sections. The first sought to find out how CWS managers view forecasts in general and if they use weather and climate forecasts in their planning and operations in particular. The second section aimed at determining system sensitivity and vulnerability to weather and climate. The third tried to establish the ability of the managers to understand and use climate forecasts. Finally, the fourth section gathered basic information on characteristics of the managers and their systems.

The survey resulted in a rich source of data that we are still plumbing. For all data, we have produced simple cross-tabulations for a simplistic look at relationships among variables. Following this first-cut analysis, we have generated more sophisticated multivariate models for some sets of variables using either stepwise multiple regression or logistic regression, depending on the level of data. We will continue to create multivariate models from this resource.

Besides the survey and the preliminary work for it reported in section I.C. (e.g., focus groups and work with professional associations), we have engaged in two other significant activities. To convey climate forecast information in units that managers value and understand (and may be required to follow by state drought emergency-management systems), we developed secondary forecast products (i.e., Palmer drought indices) using primary forecast products (i.e., NOAA temperature and precipitation climate forecasts). We will use these familiar indices in upcoming work with stakeholders.

Another significant activity that we carried out grew from our interest in the vulnerability of CWSs to severe weather and climate events and the decisions that CWS managers make to reduce that vulnerability. This secondary, complementary work addressed issues of expert knowledge and uncertainty and at the same time assessed vulnerability by developing Bayesian inference models for several CWSs in the Pennsylvania SRB. Data to develop the models came from (1) study of how CWSs work from an engineering perspective, (2) collection and analysis

of hydroclimatic and water quality violation data, and (3) elicitation of expert knowledge through interviews of CWS managers.

B. Summary of any preliminary findings

The analysis of the survey returns is not complete and the emerging picture is complex. Still, we feel confident in the following findings. Although they reflect the results of the Pennsylvania SRB and South Carolina surveys, these findings probably extrapolate to the humid eastern United States.

CWS managers who have not experienced significant impacts from weather or climate in the last five years do not expect to experience adverse effects from weather or climate in the next ten years. In contrast, managers who have suffered at the hands of weather and climate in the recent past do expect weather- and climate-related problems in the future. In other words, CWS managers who have not experienced problems have low risk perceptions; those who have experienced problems have heightened risk perceptions.

A related point is that in both states, roughly twice as many systems have suffered from droughts as have suffered from floods in the last several years. Consequently, many managers see their systems as vulnerable to droughts but relatively invulnerable to floods, again demonstrating that experience with adverse events heightens risk perceptions.

Our work on Bayesian inference models revealed that the largest determinant of a system's vulnerability to weather- or climate-related water quality problems is operator decision-making. When combined with our survey results, this finding suggests an association between real vulnerability, perceived vulnerability, and operator knowledge and expertise. In other words, CWS managers who have experienced adverse weather and climate know that their systems are vulnerable.

CWSs that have experienced weather- and climate-related problems tend to derive their water from surface sources, whereas groundwater systems are more likely to be insulated from these problems. Although the pattern is complicated in South Carolina, it is simple in the Pennsylvania SRB: most smaller CWSs are groundwater systems and all but two of the larger CWSs are surface water systems. Thus, the managers of large Pennsylvania CWSs—which provide water to a large proportion of the population—perceive their systems as vulnerable to weather and climate. In South Carolina, size is not an important determinant of perceived vulnerability—only the managers' experience with weather and climate.

Perception of vulnerability (and therefore experience with adverse weather or climate) proves to be key to the potential adoption of climate forecasts. The survey results show that in South Carolina, perceived vulnerability is the only variable significantly associated ($p=0.001$) with interest in climate forecasts. In the Pennsylvania SRB (where there is a dichotomy between small, groundwater systems that seldom feel the effects of weather and climate and large, surface water systems that do feel adverse effects), size, source, and perceived vulnerability are significantly associated with likelihood to adopt climate forecasts.

The take-home message from the survey is that CWS managers are willing to use climate forecasts, but only if they think their systems are likely to experience adverse weather or climate. At least in the Pennsylvania SRB, these managers tend to oversee large, surface-water systems. We note that these managers serve most of the population, are better educated, and are likely to receive their information over the Internet. The findings suggest that, at least at first, future research should focus on designing Web-based forecasts for managers of large CWSs.

C. Papers and Presentations

Refereed papers

O'Connor, R.E., B. Yarnal, R. Neff, R. Bord, N. Wiefek, C. Reenock, R. Shudak, C.L. Jocoy, P. Pascale, and C.G. Knight (1999). Weather and climate extremes, climate change, and planning: Views of community water system managers in Pennsylvania's Susquehanna River Basin. *Journal of the American Water Resources Association* **35**, 1411-1419. [Note: this paper resulted from pilot research we did in preparation for this project; therefore, we consider it part of this project.]

O'Connor, R.E., R. Bord, K. Dow, and B. Yarnal, 2001. Risk perceptions of natural hazards: Community water system managers in Pennsylvania and South Carolina. In: *Risk-Based Decision-making in Water Resources IX*, YY Haimes, DA Moser, and EZ Stakhiv, editors, American Society of Civil Engineers, Reston, VA, 87-95.

Conference Papers

Bord, R.J., R. O'Connor, B. Yarnal, A. Fisher, R. Shudak, and C. Reenock (1999). Factors influencing community water system managers' perceived vulnerability to system disruption. Science into Policy: Water in the Public Realm, American Water Resources Association Summer Specialty Conference, Bozeman, MT, June 30-July 2. [Note: this conference paper resulted from pilot research we did in preparation for this project; therefore, we consider it part of this project.]

Dow, K., 2001. Vulnerability of community water systems. Annual Meeting of the Association of American Geographers, New York, NY, February 27-March 3.

Dow, K. and G.J. Carbone, 2001. Use of long-lead climate forecasts for water system management. 2001 South Carolina Environmental Conference, Myrtle Beach, South Carolina, March 18-21.

Dow, K. and G. Carbone, 2002. Confidence in weather and climate forecasts. Annual Meeting of the Association of American Geographers, Los Angeles, CA, March 19-23.

Dow, K., S.L. Cutter, G.J. Carbone, B. Yarnal, R. O'Connor, and D. Bord, 2001. The potential of long-lead climate forecasts to reduce local vulnerability to variations in interseasonal climate, Fourth Open Meeting of the Human Dimensions of Global Environmental Change Research Community, Rio de Janeiro, Brazil, October 6-8.

O'Connor, R., K. Dow, B. Yarnal, C. Jacoy, G. Carbone, and A. Heasley, 2002. Who wants climate forecasts? Community water system managers' perceptions of their need for climate information. Mississippi River Climate and Hydrology Conference, American Meteorological Society, New Orleans, LA, May 13-17.

Yarnal, B. R. Bord, R. O'Connor, A. Fisher, C. Reenock, R. Shudak, N. Wiefek, and R. Neff, 2000. Weather and climate risk perception in community water system planning. Annual Meeting of the Association of American Geographers, Pittsburgh, PA, April 4-8.

Yarnal, B., R. Bord, B. O'Connor, K. Dow, G. Carbone, and S. Cutter, 2001. Potential use of climate forecasts by community water system managers. Annual Meeting of the Association of American Geographers, New York, NY, February 27-March 3.

Yarnal, B., R. Neff, R. O'Connor, R. Bord, A. Fisher, C. Reenock, R. Shudak, C. Knight, and P. Pascale, 1999. The response of community water systems managers to climate variation and change: A Pennsylvania case study. Specialty Conference on Potential Consequences of Climate Variability and Change to Water Resources of the United States, American Water Resources Association, Atlanta, GA, May 10-12. . [Note: this paper resulted from pilot research we did in preparation for this project; therefore, we consider it part of this project.]

Yarnal, B., R. O'Connor, R. Bord, A. Fisher, C. Reenock, R. Shudak, P. Pascale, M.L. Glassberg, and R. Neff, 1999. The response of community water systems managers to climate variation and change: A case study in Pennsylvania's Susquehanna River Basin. Open Meeting of the Human Dimensions of Global Environmental Change Research Community, Shonan Village, Kanagawa, Japan, June 24-26. [Note: this paper resulted from pilot research we did in preparation for this project; therefore, we consider it part of this project.]

Occasional publications

Fisher, A., D. Abler, E. Barron, R. Bord, R. Crane, D. DeWalle, C. G. Knight, R. Najjar, E. Nizeyimana, R. O'Connor, A. Rose, J. Shortle, and B. Yarnal, 2000. *Preparing for a Changing Climate: The Potential Consequences of Climatic*

Variability and Change. Mid-Atlantic Overview. The US Environmental Protection Agency, Washington, DC, and The Pennsylvania State University, University Park, PA.

Fisher, A., D. Abler, E. Barron, R. Bord, R. Crane, D. DeWalle, C. G. Knight, R. Najjar, E. Nizeyimana, R. O'Connor, A. Rose, J. Shortle, and B. Yarnal, 2000. *Preparing for a Changing Climate: The Potential Consequences of Climatic Variability and Change. Mid-Atlantic Foundations.* The US Environmental Protection Agency, Washington, DC, and The Pennsylvania State University, University Park, PA.

D. Significant deviations from proposed work plan

There are two significant deviation from the proposed work plan. First, we decided that we will not conduct a second survey. The second survey was to follow the one-on-one work with CWS managers aimed at developing forecasts tuned to the managers' needs. The purpose of the second survey was to determine the ability of managers to use the tuned forecasts. We still intend to conduct interviews and develop tuned forecasts, but we think the survey would be overkill. We believe we can obtain excellent feedback on the usefulness of the surveys by working one-on-one with the water managers; the survey would be slow and expensive and probably would not produce significantly better feedback.

The second significant deviation from the work plan results from the tremendous professional success that each of the investigators have met during the course of the grant. PI Yarnal became PI of a large NSF SBE Infrastructure Grant and the Director of Penn State's Center for Integrated Regional Assessment. Co-PI O'Connor became Program Director of NSF's Decision, Risk, and Management Sciences Program. Co-PI Dow is on leave to run a major international project for the Stockholm Environment's Risk and Vulnerability Assessment Programme. Co-PI Carbone took a leave to the National Center for Atmospheric Research. Co-PI Cutter served as Vice-President, President, and Past President of the Association of American Geographers. Co-PI Bord retired. As a result of these successes and the unexpected time commitments that they entailed, the research is approximately one year behind schedule. *We therefore request a one-year no-cost extension to this grant.*

IV. Relevance to Human-Environment Interactions

A. Contributions to the Use of Climate Information in Decision-Making

This project has focused on the perceptions of eastern CWS managers. We have shown that the CWS managers most likely to use climate forecasts are those who

perceive their systems to be vulnerable in the future because they have experienced the adverse effects of weather and climate in the past. Although not universally true, these managers tend to work at large CWSs supplied by surface water; they tend to be better educated and technologically savvy.

These findings are intrinsically important because tens of millions of Americans receive their water from such systems. If we assume that climate information can help this set of decision-makers deliver water to large populations more reliably and safely, then it is important to understand what might motivate them to use climate information.

The research is also important for the use of climate information in decision-making more generally. On the one hand, we have shown that it is possible to identify who is likely to use climate information and what might motivate these individuals to do so. On the other hand, we have demonstrated that not all decision-makers are motivated to use climate information, even if they might benefit from its use.

Thus, the findings suggest the efficacy of survey methods. We have shown that surveys are appropriate for identifying "low hanging fruit"; that is, decision-makers with vital societal roles who are likely to use climate information. The findings also suggest that surveys can identify more difficult cases; that is, decision-makers who are unlikely to use climate information because they lack the motivation to do so. Our survey revealed, for instance, that it would be more effective to approach the small pool of managers who work at large surface water systems (and who serve most of the population) than to tackle the large pool of managers who work at small groundwater systems (and who serve a much smaller population).

B. Relationship to Previously Funded HDGEC Research

The base of past and present HDGEC research and funding that we bring to the table greatly enhances this research. O'Connor and Bord have extensive experience conducting surveys of people's perceptions of the environment, especially of global warming. Dow is a leader in vulnerability research, both in the hazards and HDGEC paradigms. Yarnal is an authority on the local and regional impacts of climate variation and change. Among them, they have accrued considerable HDGEC funding from NSF, NASA, EPA, NOAA, state agencies, NGOs (e.g., MacArthur), and international bodies. Currently, O'Connor is Program Director at NSF's Decision, Risk, and Management Science Program, Dow is working at the Stockholm Environment Institute's Risk and Vulnerability Programme (on leave from the University of South Carolina), and Yarnal is Director of Penn State's Center for Integrated Regional Assessment.

Specifically, this work grew directly from the intersection of an EPA STAR grant to study the vulnerability of hydrology and water resources to climate variation and change, the EPA-funded Mid-Atlantic Regional Assessment, and the NSF-funded Methods in Integrated Regional Assessment (an HDGEC center grant).

Since this research started, additional support for has come from the NSF SBE Social Science Infrastructure grant to develop Human-Environment Regional Observatories (funded by the NSF Geography and Regional Science Program and HDGC Program and by NOAA-OGP's HDGC Program). Please note that our success in HDGEC research and research administration since the start of this grant has added immeasurably to the richness of the study, but has also slowed its pace.

C. Explicit Contributions of the Project the Following Areas of Study

1. Adaptation to long-term climate change. None

2. Natural hazards mitigation. None

3. Institutional dimensions of global change. None

4. Economic value of climate forecasts. None

5. Developing tools for decision-makers and end-users. The goal of the next phase of the project is to create forecast products "tuned" to the needs of the CWS managers of large surface water systems.

6. Sustainability of vulnerable areas and/or people. An objective of this study is to identify CWSs that are vulnerable to the impacts of weather and climate. Identification of vulnerability is a necessary first step in reducing vulnerability and enhancing sustainability.

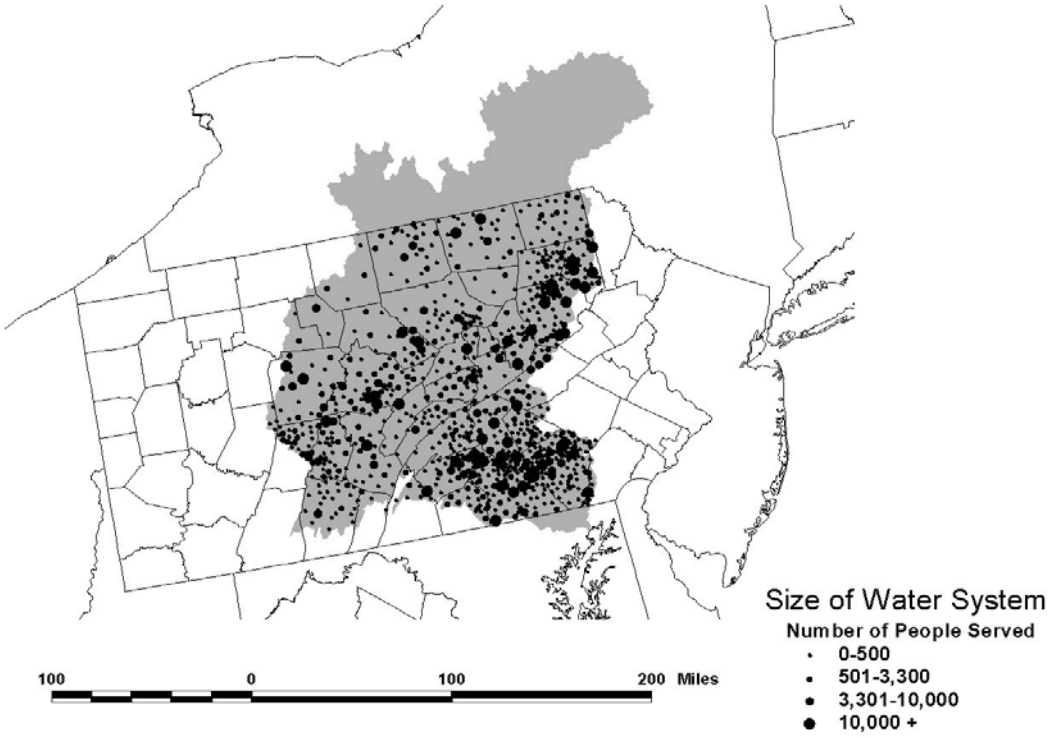
7. Matching new scientific information with local/indigenous knowledge. A premise of this research is that climate forecast information can enhance the knowledge and expertise of CWS managers, and therefore improve their decision-making. Yet, each CWS manager has remarkable knowledge of his domain and is the best judge of how to apply information to his or her decision-making. Thus, this research tries to match climate forecast information with the specific needs of CWS managers.

8. The role of public policy in the use of climate information. None

9. Socioeconomic impacts of decadal climate variability. None

10. Other (e.g., gender issues, ways of communicating uncertain information) . None

V. Graphics



The Susquehanna River Basin, with locations and sizes of community water systems in the Pennsylvania portion of the basin